
The Metal Compression Forming Process

by

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Introduction

With the constant drive toward cost-effective, high strength, net-shape casting methods by the transportation industry, Precision Metal Forming has developed a new and innovative process called Metal Compression Forming (MCF). MCF integrates the deceptively simple concept of solidification of metal under direct pressure with closed die forging and low-pressure permanent mold fill technologies. This hybrid process therefore combines the advantages of traditional direct squeeze casting and low-pressure permanent mold casting.

MCF offers the ability to manufacture high strength, high integrity castings in safety critical applications such as structural and chassis components. The MCF process also represents a more cost effective alternative to the currently-emerging indirect squeeze casting and semisolid forming technologies. Some of the benefits of MCF are reduced capital costs as compared to semisolid forming and indirect squeeze casting, cycle times comparable to cold chamber die casting and 'multiple-on' part capability not possible with traditional direct squeeze casting. In addition, MCF offers more flexibility in terms of castability of cast and wrought aluminum alloys where isotropic properties and excellent strength-to-weight ratios are a necessity.

This paper will present and summarize the current state of development, as well as briefly contrast and compare some of the competing technologies of MCF.

Process Description

MCF is a hybrid process combining technologies used in closed die forging, low pressure permanent mold, and traditional direct squeeze casting. The MCF process is preferably implemented in a vertical orientation, however in some cases horizontal machine orientation may be used. The die concept parallels that found in precision forging of aluminum alloys where the bottom die is a "finisher" die and the top die is a "blocker" punch. The top die of the MCF process is also a "finisher" die, but it moves as does the top die in the precision aluminum forging process. In the MCF process the top die which contains the ejection system is positioned so that its linear travel will compensate for the solidification shrinkage which occurs during part forming.

The metal delivery system uses the low-pressure bottom fill methodology. However, substantial differences exist in the gating design as compared to conventional

low pressure permanent mold. A key difference in the design of the gating system is the hydraulically actuated or thermally activated shut-off pin. The shut-off pin ensures that each cavity has the correct volume prior to pressurization. This method has proven to be accurate to within 1% of the required component fill volume, solving a major hurdle encountered in traditional direct squeeze casting which uses metering systems with accuracy typically no better than 3%.

The MCF process can be broken down into three steps:

1. The top die half is closed to a predetermined position controlled by initial positive stops. This position is an offset determined by the linear travel necessary to compensate for the solidification shrinkage.
2. After the top die half is positioned the mold cavities are filled via the low pressure system. As the mold cavities are filled careful attention is given to the thermal management for controlling directional solidification. After the cavities have been filled with the molten alloy, the gates to each of the cavities are closed. In some instances a vacuum may be applied during the fill stage for evacuation of the cavities.
3. Based on the part geometry a pressurization dwell time and duration is executed by closing the top die until the final positive stops are mated. The pressurization duration is typically determined to be equal or to exceed the time necessary for the component temperature to drop below the solidus temperature of the alloy and also result in the force feeding of any potential shrinkage cavities. The result is a very near 100% dense net-shape part with an extremely fine microstructure, yielding isotropic properties at or exceeding precision aluminum forging. After part formation and the necessary dwell to achieve ejection temperature, the components are ejected. Part removal and die preparation are similar to those used in conventional die casting. The cycle then repeats.

Design Considerations

Shape, complexity, size and section thickness are the principal variables that affect the MCF process, and its suitability to manufacture a particular component. Achieving detailed features in the part and tooling requires the use of simulation based design methods to balance the thermal mass and stress pattern in the

various casting sections. Process simulation is also used to prevent alloy segregation in alloy systems that have wide freezing ranges.

Certain design rules have been developed for component geometries made using the MCF process. These considerations are presented below:

- The design method must consider the taper requirements (generally 1-2°) for those surfaces on the moving die surfaces.
- The designer should control the sectional variations such that they are not greater than 1:3:1.
- Section thicknesses from 0.12" to 2.5" are allowable, however design should optimize heat flow balance.
- Dimensional repeatability of +/- .002" can be used as a design baseline.
- Most common cast and wrought aluminum alloys can be considered for applications using the MCF process.
- Metal yields are typically in the better than 90% range.

The MCF process offers the ability to form casting as well as wrought aluminum alloys. In casting alloy compositions the MCF process can typically produce components with substantially better mechanical properties than conventional casting methods (See Table 1). The improvements reflect the fine-grain structure, excellent segregation, and elimination of microporosity. While still under development, the MCF process also exhibits strong potential for forming of wrought aluminum alloys (See Table 1). Conventional precision forging achieves mechanical properties which have longitudinal and transverse variations, whereas the MCF process achieves isotropic properties equal to or exceeding precision forging. MCF's properties result from the fine cast microstructure produced by pressurized solidification of the wrought aluminum alloys.

Table 1 - Mechanical Properties for MCF

<i>Alloy</i>	<i>UTS</i>	<i>YTS</i>	<i>Elongation</i>
A356(T6)	45 ksi	37-38 ksi	16-18%
6061(T6)	49 ksi	46 ksi	8%
7075(T73)	69 ksi	63 ksi	4%

As with indirect squeeze casting and semisolid forming tooling design for the MCF process can present problems if strict engineering principles of heat and stress management are not employed. The pressure which solidifies the aluminum alloy can have a significant effect on certain die geometries. This impact, which is caused by the constant contact at the interface between the aluminum and the tool steel, can promote thermal fatigue in the tool steel. Composite die designs with inserts and temperature control passages are therefore used in the MCF process to prevent initiation of thermal fatigue. Studies have shown that inserts with moderately complex geometries will have performance in the range of 40,000-50,000 cycles.

Research and Development is currently being performed to enhance die life for the MCF process. Two current areas of research are the use of die materials with higher thermal conductivity values and the electrostatic application of the die release agent. Both areas are expected to yield extended tool life by reducing the cyclical thermal shock. In summary, intelligent tool design is required to amplify the advantages of the MCF process without comprising performance or economics.

Capital Investment

The MCF process uses standard foundry equipment and raw materials which support conventional die casting and low-pressure permanent mold. The MCF process, typically engineered in a vertical orientation, uses a machine capital cost comparable to cold chamber die casting. MCF uses the benchmark of approximately \$1,000 for each ton of hydraulic clamping force required. MCF pressures and associated clamping force requirements are determined using the simple ratio of (Load/Projected Area) for the component shape. Tall slender components require higher pressure than those that have a lower aspect ratio. The overall pressure range will always be considerably lower than those found in the precision forging and conventional die casting of aluminum alloys. The reduction in clamping force requirement can therefore be translated into lower machine cost and/or increased 'part-on' capability.

MCF machine amortization is further enhanced by shorter cycle times than those exemplified in the

indirect squeeze casting process. Overall, the MCF process is considerably more economical than the technology alternatives of indirect squeeze casting and semisolid forming.

Typical Applications

Historically, wrought products have been employed where strength and structural integrity is important. Whereas castings have been employed in areas which structurally are less pivotal, and where shape capabilities of the casting process can be used to economic advantage. The MCF process can be used to form a wide variety of metals into near net-shape and net-shape components. Some of the advantages are as follows:

- Process has the ability to use non-casting alloys.
- Parts possess dimensional accuracy and repeatability.
- Parts have mechanical properties characteristic of forged products, and microstructures free of porosity.
- Mechanical properties are isotropic.

- Production rate comparable to conventional cold chamber die casting.
- Parts require minimum machining.
- Possibility exists of much reduced inspection costs.
- Designers can incorporate a wide range of ferrous inserts and/or composite structures for localized property enhancement.

Conclusions

The MCF process is quickly becoming established as the next generation metal forming technique for the transportation industry. As has been presented in this paper, the MCF process represents a more cost effective alternative for currently-emerging indirect squeeze casting and semisolid forming technologies. The MCF process also offers more flexibility in terms of castability of cast and wrought aluminum alloys where isotropic properties and excellent strength-to-weight ratios are a necessity.